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External Monitoring in the Next Ten Years

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I. DRIVING FORCES IN RADIATION PROTECTION

As the radiation protection community moves through the last half of the '80s and into the next decade, we can expect the requirements for external dosimetry to become increasingly more restrictive and demanding. As in other health protection fields, growing regulatory and legal pressures, together with a natural evolution in philosophy, require the health physicist to display an increasing degree of accountability, rigor, and professionalism. The good news is that, for the most part, the technology necessary to solve many of the problems will be available or not far behind.

Regulatory changes are typified, but certainly not limited to the ICRP recommended increase in the neutron quality factor (ICRP 1985), by a factor of 2 over the values given in ICRP Publication 21 (ICRP 1973). A review of the technical issues surrounding the question of quality factor changes has been prepared by a joint task group of the ICRP and the ICRU (ICRU 1986). An increase in Q has by no means been universally accepted. The British Committee on Radiation Units and Measurements has recommended against the ICRP proposed change "for the time being" (BCRU 1986). However, they do recommend that quality factors should be recorded from now on. Other national and international organizations, such as the British National Radiological Protection Board (NRPB) and a committee of C.E.C. technical experts, are similarly cautious. The U.S. Department of Energy is currently wrestling with the issue.

Q is one example of a sense of conservatism developing in radiation protection regulatory processes. This conservatism goes hand-in-hand with a national legal experience in recent years that emphasizes the need for high-quality health physics, particularly dosimetry, as well as detailed work and exposure records. The interest in the the legal issue was exemplified by a full house at the plenary session on the subject at the 30th Health Physics Society Annual meeting in 1985. Fortunately, a recent, highly publicized landmark decision (Johnston v. United States) demonstrated that the courts are capable of dealing with highly technical issues. Although the effort and dedication shown by Judge Patrick F. Kelly may be considered heroic and perhaps atypical, nevertheless the case gives hope and encouragement to the health physicist.

As the legal, medical, and health physics professions learn to deal with the highly complex issues involved in radiation exposure litigation, new philosophies and approaches will evolve and be tested as appropriate methods for reaching decisions. A current example is the concept of Probability of Causation. Tables have been developed (NIH 1985), that estimate the probabilities that certain specific cancers are caused by previous radiation exposure. It was intended that "these tables be developed to facilitate the judicial decision-making process in providing just compensation to persons exposed in nuclear weapons tests in whom the forms of cancer associated with radiation exposure consequently develop" (Gur and Wald 1986). Although the assumptions that provide the bases for the tables result in wide ranges of uncertainty and there is concern over applying these data to estimate cancer induction risk for individual cases, they are now being adopted for use in law suits involving individual incidents of cancer formation.

From a health physicist's point of view, one of the key implications that Probability of Causation Tables present is that it will be increasingly more important to obtain dosimetric data necessary to estimate dose to individual organs in addition to uniform, whole body, or extremity monitoring. Moreover, this would require close integration of external and internal dosimetry records. At the least, it means more detailed work history and exposure records, including information on exposure conditions, radiation type, and energy distribution. It may become more important to tie the records of individuals to area monitoring and survey programs. The need to make such surveys and include measurements of radiation spectra will also be more important. Personnel dosimeters and dosimetry techniques that can yield information on radiation spectra and spacial field distribution will become quite valuable.

We have already touched on possible changes in neutron quality factor. Additional changes in Q could include low-energy betas and high L.E.T. particles such as alphas. From an external dosimetry standpoint, probably only neutrons are of a significant concern. However, the considerations that support such changes have included a significant review of the proper relationship between Q and L.E.T. One view is that lineal energy, y, is a better parameter than L.E.T. for definition of Q (Fig. 1) because y (the quotient of ε, the energy imparted to the matter in a volume of interest by an energy deposition event, and l, the mean chord length in that volume) can be instrumentally defined and directly measurable (ICRU 1986). The measurement of y is usually made with tissue-equivalent proportional counters; however, other techniques can be employed (ICRU 1983). Whether the definition of Q is based on y or L.E.T., measurements related to L.E.T. will probably continue to grow in importance.

One of the most significant developments over the last ten years has been the evolution of a new set of operational quantities for dose equivalent. A recent seminar (Booz and Dietz 1985) involved a number of fine presentations devoted to the question of operational quantities. We have seen the transition from dose equivalent based on a cylindrical phantom to the index quantities (absorbed dose index, D_I, and dose equivalent index, H_I) defined using the ICRU 30-cm-diameter tissue equivalent sphere (ICRU 1971; ICRU 1980). Dose equivalent index, however, has significant limitations for practical application. For example, H_I demonstrates angular, temporal, and energy nonadditivity (Wagner 1980). This led to a series of proposals for operational quantities that could be used in practice--dose equivalent ceiling, average dose equivalent in the ICRU sphere, dose equivalent Hd at a specified depth in the sphere, circumjacent dose equivalent, etc., (Wagner 1980; ICRU 1985).

Recently, the ICRU has presented four new operational quantities that link the concepts of expanded and aligned radiation fields to the effective dose equivalent and dose equivalent to the skin (ICRU 1985):

- Ambient dose equivalent, $H^*(d)$.
- Directional dose equivalent, $H'(d)$.
- Individual dose equivalent, penetrating, $H_p(d)$.
- Individual dose equivalent, superficial, $H_s(d)$.

These new quantities have a sound physical basis (Burlin 1985) and are compatible with the practical needs of radiation measurement and calibration programs.

External and internal dosimetry are brought together by the effective dose equivalent, H_E, introduced by the ICRP (1977). This quantity combines the dose equivalents received by specific organs or tissues, and weights the organ contributions in proportion to their relative risk:

$$H_E = \sum_i w_i H_i ,$$

where H_i is the dose equivalent to organ i, and w_i is the weighting factor (ICRP 1977). Unfortunately, H_E can not be measured; however, it can be calculated easily from measurements in many cases, and it is probably the best dosimetric quantity for assessment of biological impact from chronic exposures.

II. EXTERNAL DOSIMETRY NEEDS

The regulatory requirements and litigation pressures will combine to drive us toward instruments and techniques that provide better sensitivity, more detailed information about the radiation fields, and dosimetry records with a high degree of detail and documentation. Radiation dosimetry programs will require a gréater level of sophistication and more attention to detail. More effort will be required for area surveys to provide necessary information for characterization of radiation fields. This concept can be illustrated as need for a hierarchy of monitoring techniques (Fig. 2) in which the information available increases in proportion to the difficulty and amount of effort expended. In the past, monitoring at the higher, more sophisticated levels of the hierarchy has required a great deal of time and effort because of the equipment required to do the work. Now, however, technical developments are occurring that make such monitoring more practical and achievable with more modest investment of money and time.

From both the regulatory and legal points of view, it will be very important to develop methods of determining the dose to individual organs. This means that sufficient information about radiation spectra, field distribution, and body orientation must be available to permit estimation of doses to specific organs. Furthermore, record keeping technology will need to include the ability to combine dose estimates from external monitoring and internal dosimetry. This is likely to result in sophisticated data basing that includes results from area surveys, personnel dosimeters, whole body counting, and bioassay. The corollary is that record keeping systems must have at least some degree of national standardization and intercomparability to permit effective transfer of information between facilities. The Department of Energy has recognized this for some time and is in the process of developing a system for centralized records maintenance.

Photon Dosimetry

It can be argued that the state of photon dosimetry is in relatively good shape. The basic technology behind thermoluminescent dosimeters and other detection mechanisms has been refined for many years and is well understood. There are number of dosimetry services, including those at major laboratories, capable of producing high-quality results. However, data from these services provide measurements of dose to the dosimeter. Extrapolation to organ doses, particularly for low energies, is not necessarily straight-forward, and such information has not normally been part of the dosimetry record. Steps such as use of additional dosimeters, radiation transport calculations, or detailed area surveys are rarely taken to make such estimates. Moreover, it remains difficult to measure x-rays and low-energy gammas accurately, or at least to the accuracy that will be required ten years from now.

Neutron and Beta Dosimetry

Neutron and beta measurements are specialized, when compared with photon dosimetry, and they remain partially unsolved dosimetry problems. The most common neutron dosimeters are TLD albedo detectors. They are quite sensitive (<100 µSv); however, they suffer from severe energy dependence (Alsmiller and Barish 1974), resulting in serious inaccuracies related to changes in spectrum. CR-39 track etch detectors have much better energy dependence characteristics (Tommasino and Harrison 1985) and an adequate sensitivity (100-200 µSv). However, with an increase in fast neutron quality factor, the sensitivity would become marginal to inadequate. Moreover, track detectors, including CR-39 have a severe orientation dependence. The best results are currently obtained with combination dosimeters (Sims and Dickson 1985) that incorporate both albedo detectors and CR-39, using the advantages of each detection mechanism. Moreover, with two elements that have widely different energy response functions, it is possible to perform some very simple spectrometry. That feature will become more important in the next ten years.

Nearly all of the survey instruments currently used for neutron monitoring use thermal neutron detectors with moderators (Andersson and Braun 1962; Hankins 1962). They have the necessary sensitivity and, with the exception of an overresponse to intermediate energy neutrons (Cosack and Lesiecki 1985), adequate accuracy. However, because of the moderator, they are quite heavy and bulky, which places some limitation on their use in practical monitoring situations. An increase in quality factor of 2 over the full energy range would not affect their energy response; however, the sensitivity would be decreased proportionally. The primary need is for an instrument with reduced weight. However, some ability to characterize the energy spectrum will become important.

Beta measurement in some ways is more difficult than either neutron or photon dosimetry. The radiations are weakly penetrating, fields are highly non-uniform, and the spectra distributed. Dosimeters that respond to betas also respond to photons, often making differentiation between betas and x-rays a very difficult task. Beta dosimeter development frequently emphasizes use of thin detectors, equivalent to beta ranges, to minimize photon energy deposition and interference. However, thin detectors commonly suffer from lack of sensitivity (Christensen 1986), as well as being fragile and difficult to handle. As a result, most dosimeters currently in use are too thick (Christensen 1986).

Since beta fields tend to be highly nonuniform, with rapid changes over relatively short distances, the use of beta survey instruments provides area survey results that are less definitive than for photons or neutrons. For the most part, they are indicators of contaminated surfaces, and the results can not be easily related to personnel exposure. However, through the use of electronics and special detector design, beta survey instruments can provide effective photon rejection and be used to obtain spectral information.

Fortunately, short beta ranges, good source material control, and low values of Q prevent inadequacies of current measurement systems from being a widespread dosimetry problem. However, there are facilities, including nuclear fuel reprocessing operations, that experience beta exposure as a health physics and dosimetry issue. We still lack beta dosimeters that have sufficient photon discrimination and accuracy. As for gammas and neutrons, beta spectral information will also become more important.

Calibrations

The accuracy of a dosimetry system can be no better than that of the calibration program used to support it. Today, calibration technology may be the strongest link in most dosimetry programs. This is in part because the calibration laboratory has the luxury of using equipment and techniques not available for field radiation measurement.

In addition to sophisticated instrumentation, there have been valuable developments in the radiation fields available for calibration. Well calibrated, moderated neutron fields, including specification of a moderated

^{252}Cf spectrum that more closely simulates power reactor containment spectra, are now available (Griffith et al. 1978; Schwartz and Eisenhauer 1981; ANSI, 1983; Sims 1986). Development of monoenergetic neutron fields help contribute to our understanding of instrument response (Schwartz and Eisenhauer, 1980; Perks et al. 1986). The considerations involved in the calibration process are well understood (Eisenhauer et al. 1986). Well calibrated beta source sets are now readily available. X-ray fluorescence systems have been developed for monoenergetic, low-energy photon calibrations, including a selectable energy, transmission anode x-ray (TRAX) system that uses target self-filtering to clean up the scatter spectrum (Cate and Huntzinger 1985).

Recordkeeping

During the next ten years, there will be increased movement toward records keeping systems that lead to a much better access to information for a variety of needs--trend analyses, legal inquiries, effective integration of external and internal dosimetry records, efficient exchange of radiation histories between employers, etc. The U.S. Department of Energy has been working in that direction for some time through the development of the Safety Performance Measurement System at the Idaho National Engineering Laboratory. This system includes both radiation- and nonradiation-related safety information. However, the radiation information is being embodied in the appropriately named Radiation Exposure Module (REM), also referred to as the Radiation Exposure Information Reporting System (REIRS).

In summary, dosimetry needs for the next decade will include--

- o Improved dosimeter accuracy.
- o Improved dosimeter sensitivity.
- o Capability to obtain information about radiation field characteristics, particularly energy spectra, both from dosimeters and survey instruments.
- o Improved survey and dosimetry record keeping systems.
- o Improved techniques for estimating organ doses.

Although the degree of these needs is different for different radiation types, they are generally true for photons, neutrons, and betas.

III. BETTER HEALTH PHYSICS THROUGH NEW TECHNOLOGY

Microelectronics

It requires little imagination to say that developments in microelectronics will have a profound impact on the ability of the health physicist to do his or her job in the 90's. We have already witnessed an evolution of portable health physics instruments using highly sophisticated microcircuitry. They are lighter, smaller, smarter, more rugged, and have longer battery life than their predecessors of the 70's. Instrument size is now determined by the size of the detector needed to achieve the necessary sensitivity and the controls, which must be large enough to be easily manipulated. In fact, Erkkila (1984) recently described a wristwatch size dosimeter/dose rate meter (Fig. 3).

In general, size and weight reductions have been achieved that meet the needs of the health physics community. The newest advances are in the degree of information sophistication that an instrument can provide. Capabilities that were considered as limited to laboratory and research instruments ten years ago are now appearing in easily portable instruments. It is possible and will become even easier to make field measurements of radiation quality and energy spectra with instruments that are highly portable and relatively rugged. Advertisements for commercial survey instruments are beginning to describe their products as "smart" (Erkkila 1984). Newer instruments will be increasingly more sophisticated so that valuable information can be obtained by professionals or technicians who do not need an unusual degree of specialized expertise in instrument calibration and use, and data interpretation.

Instruments of this class have already been developed to address neutron and beta field characterization needs. A microprocessor-based neutron survey meter (Fig. 4) having weight reduced by a factor of 2, together with enhanced versatility using detectors placed in small moderators (62.5 and 100 mm in diameter), has recently been demonstrated (Mourges et al. 1985). Through the use of a data unfolding algorithm in the microprocessor, the authors are able to determine absorbed dose, dose equivalent, and quality factor.

Even more significant size reduction has been reported using tissue-equivalent proportional counters (Brackenbush and Endres 1985; Brackenbush et al. 1985; Nguyen et al. 1985). Instruments of this class can be reduced in size to the point that they can be used as personal monitors. Moreover, use of tissue-equivalent proportional counters, together with suitable microprocessor software, provides the user with the ability to estimate radiation quality. Given this information and the flexibility of making software changes, the user is able to adjust to changes in quality factor without the instrument becoming obsolete. In addition, valuable data can be obtained to help determine organ dose. One truly begins to approach the concept of a "Total Dose Meter" (Fig. 5) that can deal with photons and neutrons simultaneously (Brackenbush et al. 1985).

Beta instruments are also advancing in sophistication. A collaborative effort involving the Department of Energy Environmental measurements Laboratory, Los Alamos National Laboratory, and the Livermore National Laboratory (Hajnal 1986) has produced a light-weight scintillation detector spectrometer-dosimeter for beta particles (Erkkila 1984) (Fig. 6). Martz et al. (1986) report development of a portable beta spectrometer for measurement of the dose rate at 0.07 mm and 10 mm tissue depths using an external multichannel pulse height analyzer.

Solid state detectors have been used for some time to detect photons and beta particles, resulting in significant reduction in instrument size and weight. However, gas filled detectors still predominate, primarily because of low cost and good sensitivity. Some efforts have been directed toward use of diodes for neutron measurement (Lucas 1977; Swinehart and Swartz 1979; Tyree and Falk 1982), the most recent of which (Eisen et al. 1986) is also intended for use as a gamma detector (Fig. 7). However, success of these dosimeters is hampered by insensitivity to low-energy neutrons, high cost, and severe directional dependence for neutrons below a few MeV. A recent study cited potential advantages of a hydrogenous semiconductor for neutron detection (Brackenbush and Quam 1985), summarized current obstacles to development of such a detector, and called for more effort in this area.

Perhaps the most fascinating, yet untapped application of solid state devices is detection of charged particles using MOS or RAM microelectronic elements. Two classes of phenomena have been proposed as potentially sensitive radiation detectors. First, Tommasino et al. (1977) proposed the detection of breakdowns in thin film MOS capacitors (Fig. 8) for detection of heavy charged particles (fission products, heavy recoils, and alpha particles). Although others (Smirnov and Eismont 1978; Gangrskii et al. 1980; Dorschel et al. 1983; Griffith et al. 1978) have investigated the breakdown phenomenon, a practical system has not been developed.

An even more intriguing proposal (Davis et al. 1982; Winters 1983; Thomson et al. 1983) is the use of radiation-induced errors in MOS Dynamic Random Access Memory (DRAM) components as charged particle detectors. Since the individual cells are a few µm in diameter and about 1 µm thick, they approach biological cellular dimensions and offer the possibility of solid state microdosimetry. Sensitivities below 1 mGy have been demonstrated (Thomson et al. 1983), and, since they become more sensitive with decreasing cell size, personnel dosimetry with MOS components appears to be quite feasible. In fact, it is possible to envision a wrist watch neutron solid state dosimeter (if not a spectrometer) based on MOS detectors.

New Detection Mechanisms

In the 1970's, studies began on a new class of track detector that uses media that can be liquid (Skripov 1974), soft gels (Apfel and Roy 1984) or elastic solid materials (Ing and Birnboim 1985). The superheated drop or bubble-damage detectors are prepared by incorporating tiny superheated droplets of a gas or liquid throughout the medium. When a heavy charged particle (such as a neutron-induced recoil) passes through the medium, it triggers a release of the energy stored in the droplet, which causes it to explode (Fig. 9). The volume of gas liberated, if the medium is liquid, or the number of bubbles created, if it is solid, can be related to the charged particle (or neutron) fluence. The sensitivity of these detectors can be controlled by the parameters of the preparation process, so that they can be made photon insensitive, but highly sensitive to neutrons. In fact, since the sensitivity can be varied, it may be possible to develop a set of detectors that could be used as a neutron spectrometer. Moreover, unlike their flat track etch detector counterparts, they are not inherently orientation dependent.

Since 1978 (Perino et al. 1979), we have seen a series of reports describing the use of electrets for both external monitoring (Gupta et al. 1985; Dorschel and Pretzsch 1986) and detection of airborne radiation (Pretzsch et al. 1986; Kotrappa et al. 1983). In principle, electrets perform as ion chambers (Fig. 10). The major difference is that they feature the use of charged insulators rather than conductive electrodes connected to a charged capacitor. Although there have been a number of reports, it is not clear that there is an advantage over existing photon dosimeters for external dosimetry, and an operational dosimetry system using electrets has yet to be reported.

However, they are simple and interesting, and future refinements could enhance their utility.

Other methods such as resonance ionization spectroscopy, which is literally able to detect single atoms (Hurst et al. 1979; Hurst 1981), and radiochromic waveguides (Kronenberg et al. 1981; Kronenberg 1982) have been proposed; however, limited effort is currently being devoted to their development. It is not clear that they could contribute anything new to the needs for organ dose determination. One interesting exception, however, is a proposed technique for measurement of dose in common fabric (Barthe et al. 1983a; Barthe et al. 1983b). Although initially suggested for accident dosimetry levels, it provides the prospect of being able to map the dose distribution on nearly the entire surface of an exposed individual.

Biological Dosimetry

Although the thrust of this review is directed toward instrumental considerations, it would not be complete without mention of the role that biological indicators can and should play in the dosimetry program. A variety of endpoints, such as chromosome aberrations, changes in blood and urine chemistry, and neutron activation of elements in blood, hair, etc. have been studied over the years (IAEA 1971; Eisert and Mendelsohn 1984). Although biological dosimetry is used for accidental exposures, it has not been adopted for routine personnel monitoring programs. This is due, in part, to lack of specificity, lack of sensitivity, and complexity of analytical procedures. However, such dosimetry is conceptually attractive because biological techniques could provide either body-averaged or organ-specific dose information, would not be severely orientation dependent, and would assure that dosimetry is always available. The most important benefit, however, would come from identification of a biological endpoint that could act as an normalizing indicator of exposure of ionizing radiation and nonradioactive toxic materials, i.e., a general dosimeter for toxic insult. As attractive as such a dosimetry system might be, it is very unlikely that we would realize it by the end of the century.

Personal Computers

It is now possible for the dosimetrist to flex computational muscle in the office that would have required a mainframe computer ten years ago. The degree of interest and magnitude of the developments in computers for health physics is witnessed by a Health Physics midyear symposium in 1985 that was devoted to computer applications in health physics (Kathren et al. 1984). Topics presented included applied health physics, instrumentation, data management, modeling, and emergency preparedness.

It is clear that, from the health physicist's point of view, the personal computer is a major step forward in data management and information power. It is now possible to perform an incredible variety of technical tasks on the desk top, including radiation transport (Larson and Dexheimer 1984), neutron spectrum unfolding (Brackenbush and Scherpelz 1984), model validation (Harper 1984), and criticality safety (Lutz 1986), as well as a host of internal dosimetry and record keeping applications (Kathren et al. 1984). There are data bases for ALARA tracking, bioassay records, radiation exposure records, radiological safety, and radioisotope inventories (Corbin 1984). D. S. Corbin

(1984) counsels that, "If we choose to be computer illiterate, we may have to find another job."

Even the programmable calculator has an impressive level of computational power. One of the world's first digital computers was the vacuum tube ENIAC, and Corbin tells us that, "Today's inexpensive pocket computers are more powerful than the ENIAC and can store more information." At least one emergency response program at a major laboratory uses a pocket calculator with printer and tape drive as a traveling computer center (Homann 1986). The same calculator is used by another laboratory for a set of health physics programs (Rittmann 1984).

Although there is an impressive level of computing power available to the individual user, the ability to exchange data between users is limited by the use of a large variety of computers and software. In 1984, there were more than 200 companies making personal computers (Corbin 1984). Although that number has been reduced, it is easy to see the difficulty in transferring information between users with different machines.

Adding to the problem caused by lack of hardware standardization, health physics software is generally developed by the user to meet specific local needs and is often not directly usable by another facility without significant, time-consuming modification. This, of course, also hampers exchange of information. However, national initiatives, such as the Safety Performance Measurement System, to collect and standardize dosimetry records will accelerate a natural evolutionary process and improve dosimetry information exchange. Moreover, gradual development of de facto standards in both software and hardware through networking with colleagues will be a positive force.

IV. RADIATION PROTECTION IN THE 1990'S

Many of the health physics challenges for the next decade are already clear. Others are only beginning to develop. It is certain, however, that it will technically be a far more demanding science, and that the administrative, regulatory, and legal pressures to provide first class dosimetry will become more intense. We will need dosimetry that is more sensitive and accurate, as well as providing more detailed information about the radiation fields. The ability to determine organ doses will be important. Uniformity, consistency, and detail will be key characteristics of an effective records keeping program.

Much of the technology necessary to meet the challenge is or will soon be available. So what could a dosimetry program include in ten years?

- In addition to the familiar, passive dosimeters, we are likely to have small, digital dosimeters that could be worn as wrist watches or lapel badges. In fact, an entrepreneur could consider a developing line of health physics jewelry. Along with photon and neutron dose equivalent, they may provide quality factor and simple spectral information.

- Lightweight survey instruments capable of detailed spectrometry and microdosimetry will be part of the instrumentation inventory.

- Specialized tracking systems could be developed and used for selected jobs having potential for high exposure. The radiation worker would wear a small transmitter on the belt that could provide the tracking system with real time position and orientation information. This information would automatically be combined with radiation field distribution data provided by fixed area monitors, yielding real-time, integrated dose. The microcomputer processing would have a level of sophistication that allows a running calculation and record of critical organ doses. An active personnel dosimeter provides simultaneous telemetered dose information for comparison, verification, and normalization of tracking system doses.

- Health physics reports will include distribution of information using floppy discs. An inventory of health physics software will augment or replace the traditional hardcopy reference library, permitting the dosimetrist the power to make desk top calculations of radiation interaction parameters, radiation transport calculations for shielding and dosimetry, and a variety of internal dose calculations.

The next ten years in external dosimetry will be challenging. We can expect to see developments that may have only been dreamed of ten years ago. Industry must be prepared to support dosimetry development. Recent years have seen a reduction in health physics research programs. A number of major laboratories involved in dosimetry development in the 60's have deemphasized or discontinued such work. That trend must be stopped if we are to meet the challenges of the 90's. Much of the work that needs to be done will be costly but cost effective when considering the regulatory and legal implications.

The radiation protection community will have to display a high degree of professionalism. Health physicists must do their part by communicating, cooperating, and coordinating to avoid expensive duplication. There a a great deal of work to be done. Regardless of the developments and changes that occur, it will be a fascinating time to be in health physics.

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FIGURE CAPTIONS

1. The defining relation between quality factor, Q, and y, the lineal energy, in 1 μm diameter sphere of ICRU tissue. For simplicity, no subscript indicating the diameter of the sphere is used for y (ICRU 1986).

2. Radiation monitoring hierarchy.

3. A wristwatch size dosimeter/dose rate meter (Erkkila 1984).

4. The DINEUTRON survey meter (Mourges et al. 1985).

5. A "Pocket Rem Meter" instrument for determining neutron dose equivalent using cylindrical tissue equivalent proportional counters (Brackenbush and Endres 1985).

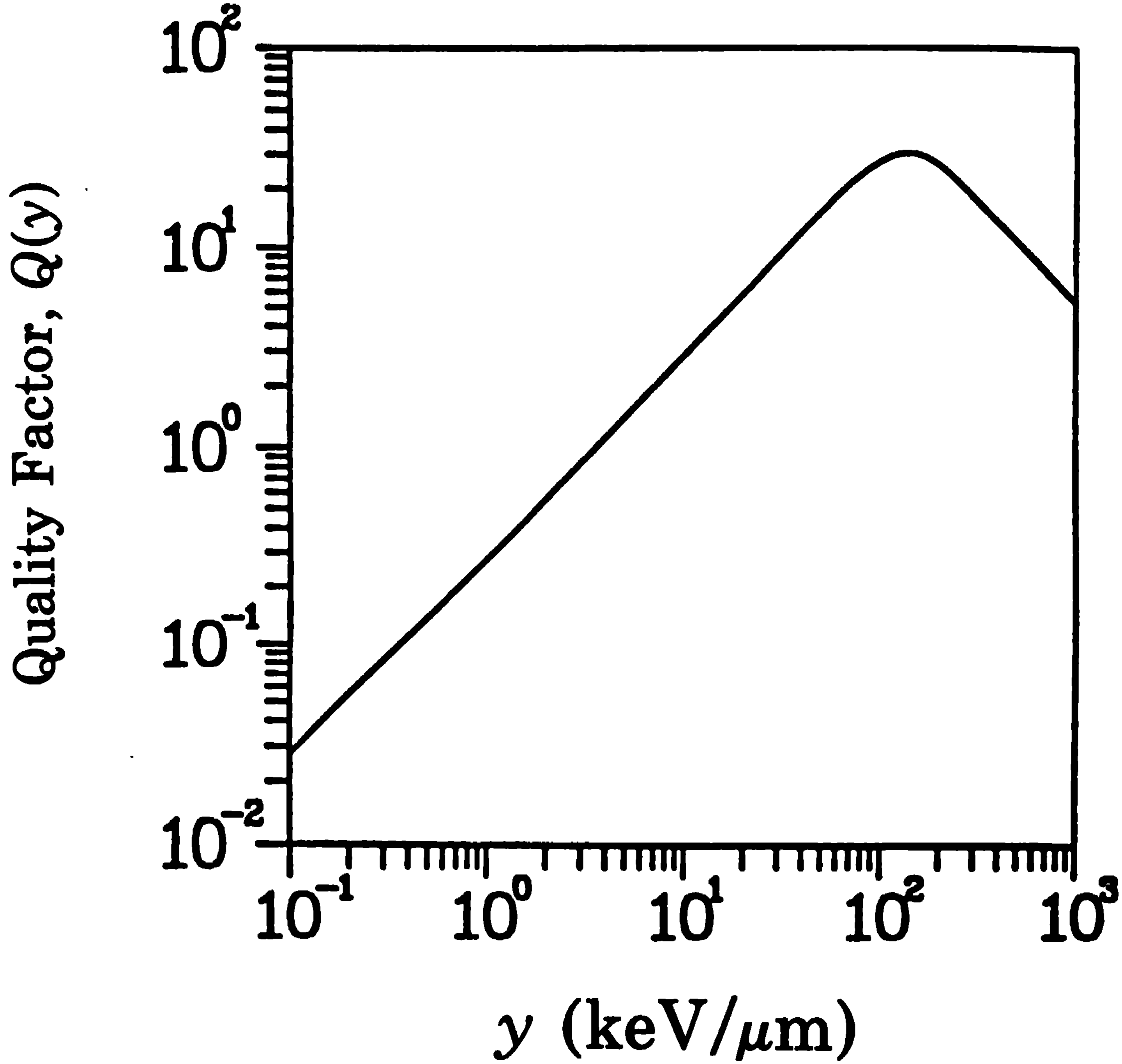
6. A portable beta spectrometer/dosimeter (Erkkila 1984).

7. Silicon surface barrier detector for mixed neutron and gamma dosimetry (Eisen et al. 1986).

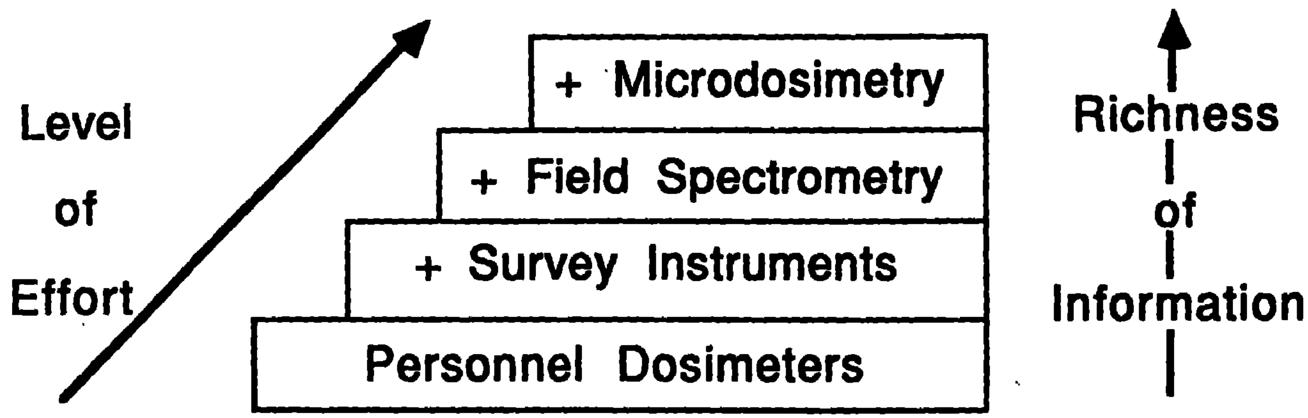
8. Circuit suggested for use of thin film neutron detector in a personnel monitor (Griffith et al. 1978).

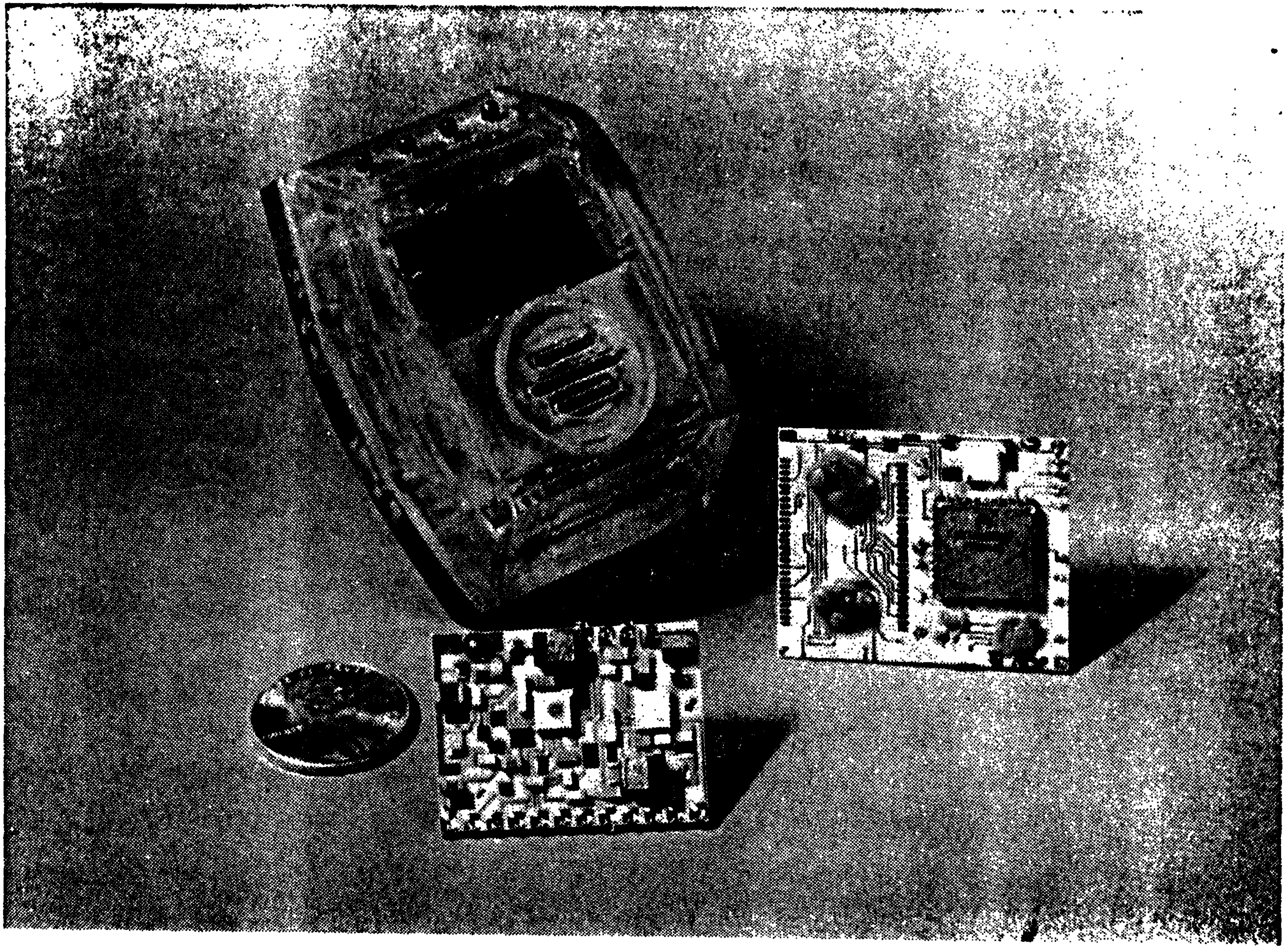
9. Schematic diagram of the bubble-damage polymer detector (Ing and Birnboim 1985).

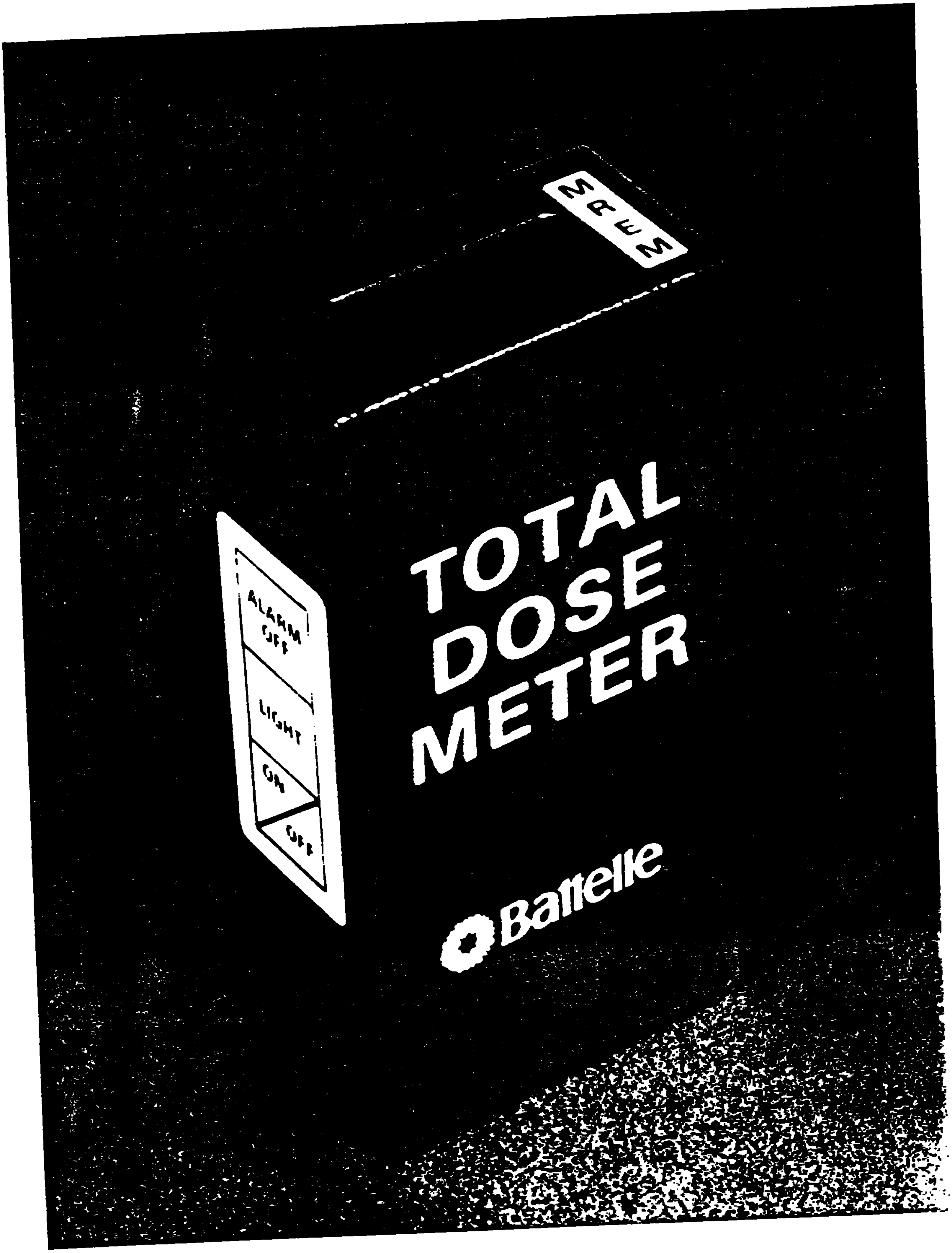
10. Schematic diagram of an electret dosimeter.



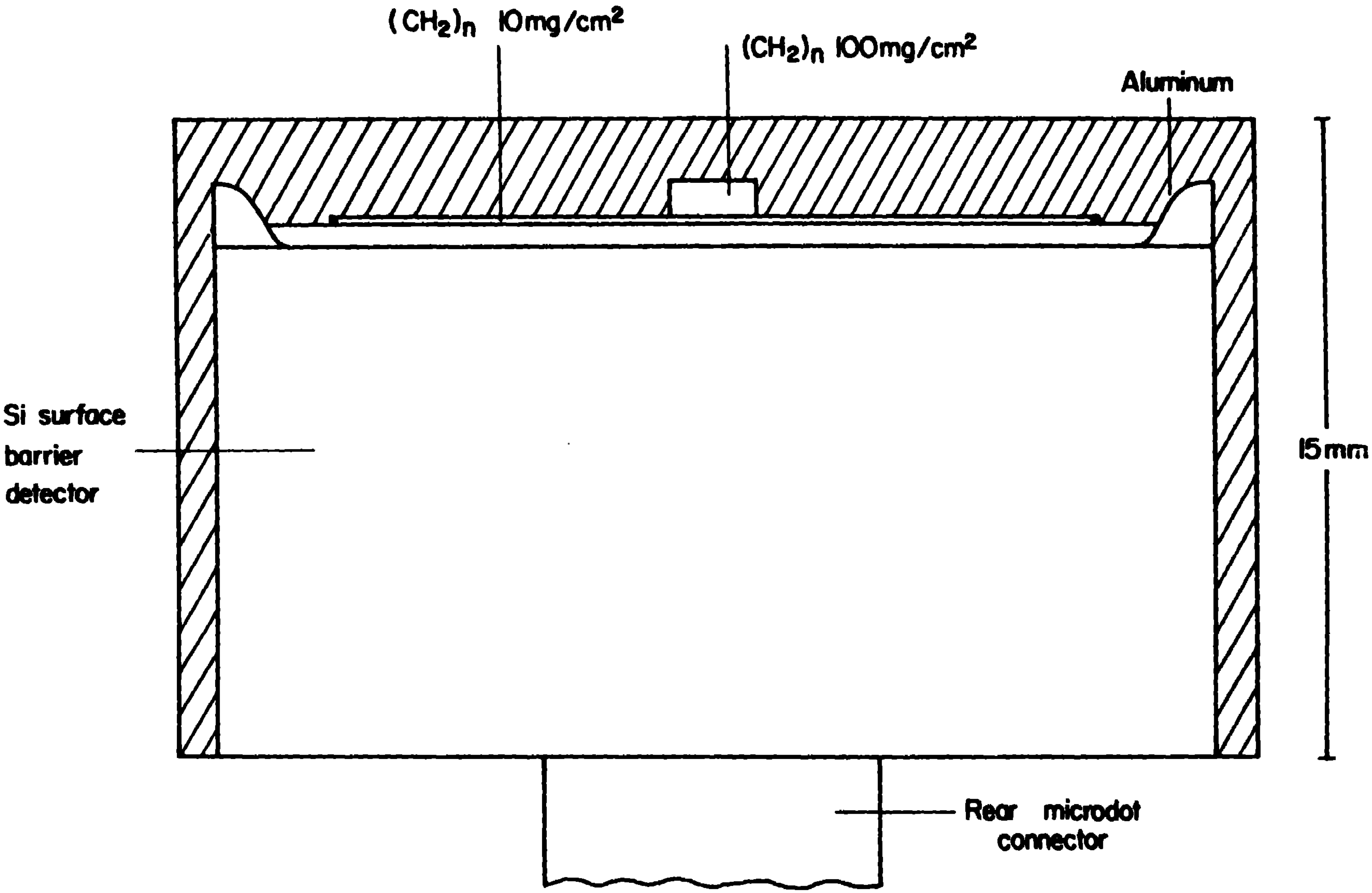
Quality Factor, $Q(y)$
10^{2}
10^{1}
10^{0}
10^{-1}
10^{-2}
10^{-1}
10^{0}
10^{1}
10^{2}
10^{3}
y (keV/μm)


Level
of
Effort
+ Microdosimetry
+ Field Spectrometry
+ Survey Instruments
Personnel Dosimeters
Richness
of
Information

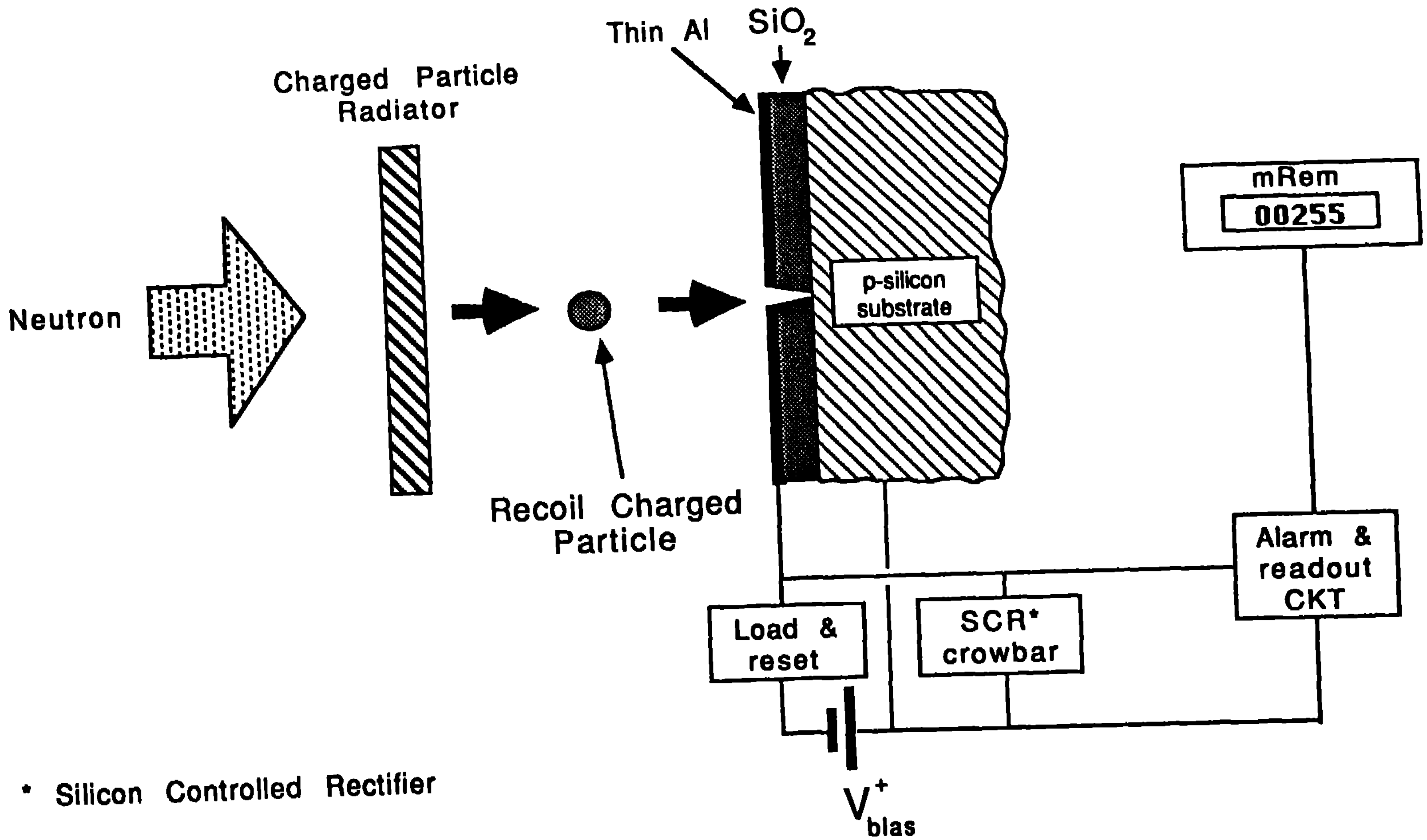



TOTAL
DOSE
METER
Battelle
ALARM OFF
LIGHT
ON
OFF

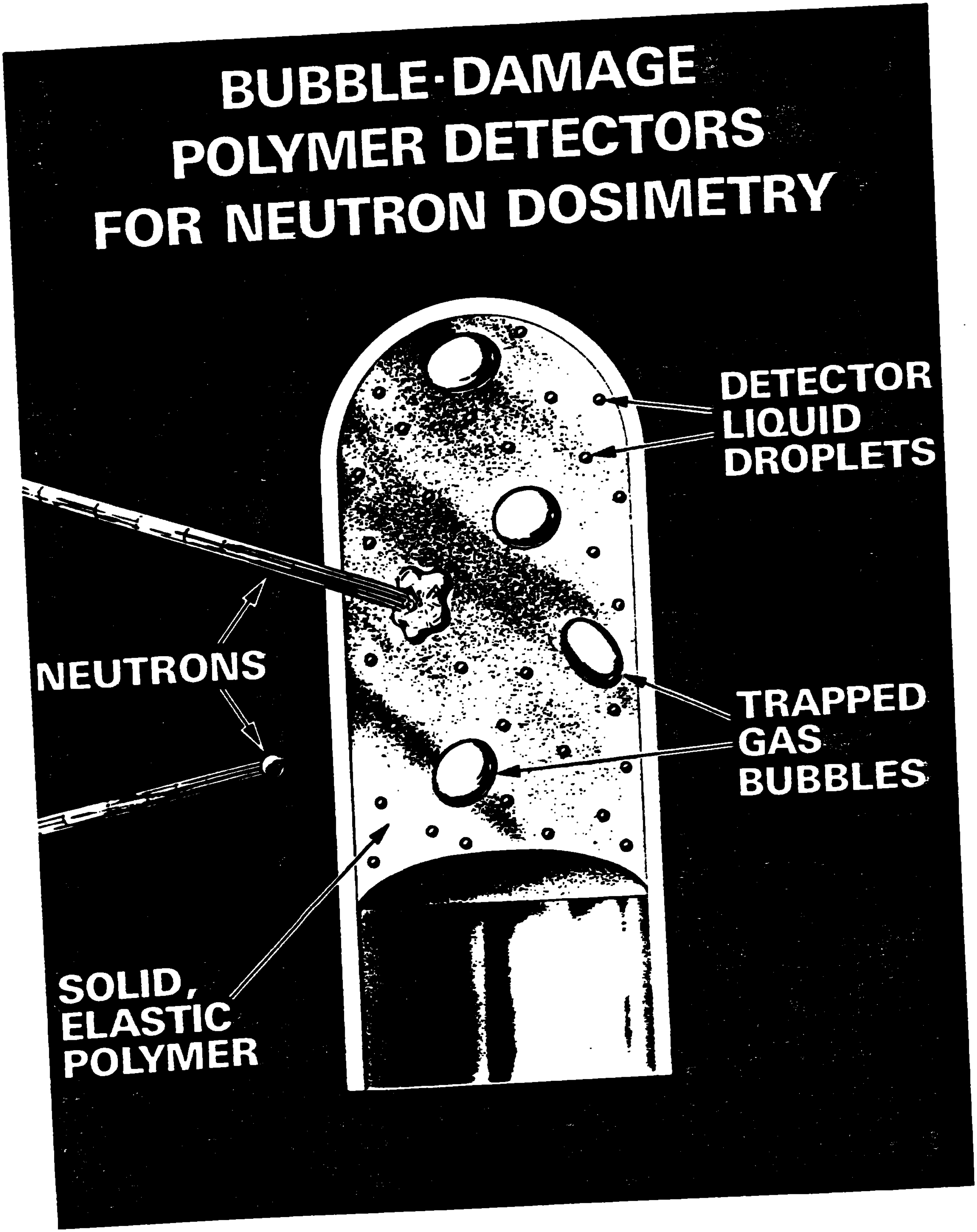

US MILITARY
EXPERIMENTAL
RADIAC

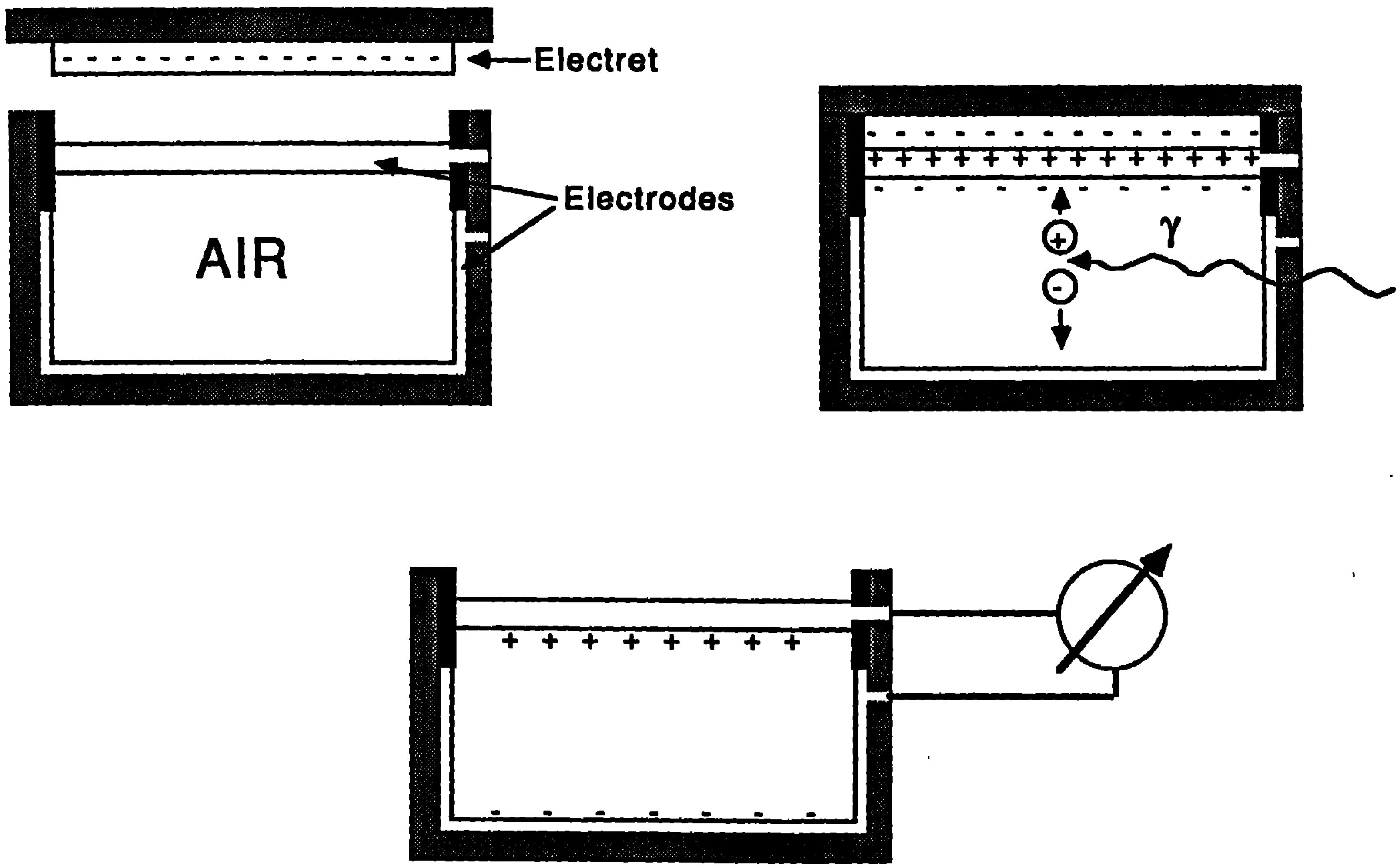


$(CH_2)_n$ 10mg/cm^2
$(CH_2)_n$ 100mg/cm^2
Aluminum
Si surface barrier detector
15mm
Rear microdot connector



* Silicon Controlled Rectifier


BUBBLE-DAMAGE
POLYMER DETECTORS
FOR NEUTRON DOSIMETRY
DETECTOR
LIQUID
DROPLETS
NEUTRONS
TRAPPED
GAS
BUBBLES
SOLID,
ELASTIC
POLYMER


Electret
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